Further development of low noise MEVVA ion source

Efim Oks and George Yushkov

High Current Electronics Institute, Russian Academy of Sciences, Tomsk, 634055, Russia

Irina Litovko

State University of Control Systems and Radioelectronics, Tomsk, 634050, Russia

André Anders and Ian Brown

Lawrence Berkeley National Laboratory, University of California, Berkeley, California 94720

ABSTRACT

Based on the idea of a space-charge-limited mode of operation, the influence of a pair of electrostatic meshes on the beam parameters of the LBNL MEVVA-5 ion source was investigated. The meshes were placed in the expansion zone of the vacuum arc plasma. Apart from reducing the level of beam current fluctuations, this mode of operation provides significant control over the ion charge state distribution of the extracted beam. These effects can be understood taking not only space charge but also the high-directed ion drift velocities into account that are the same for different ion charge states of a material. The results of simulations of the processes involved are in good agreement with the experimental results.

I. INTRODUCTION

The vacuum arc ion source commonly known as the MEVVA ion source is one kind of advanced method of generating high current, large area, metal ion beams [1]. This kind of source has been developed at a number of research groups worldwide and has found applications both in applied (surface treatment technologies [2]) and fundamental (particle accelerators [3], heavy ion fusion [4]) fields of R&D activities. These diverse areas of application call for different properties and parameters of the MEVVA ion beam. For many applications such as ion implantation and ion beam processing, only cumulative dose integral of many beam pulses is important, and this is essentially independent of beam noise and even independent of poor pulse-to-pulse reproducibility. However, for accelerator injection and heavy ion fusion, a "quiet" ion beam with practically identical pulse parameters is of paramount importance.

To solve the "noise problem" of the vacuum arc ion source, Humphries and co-workers suggested ion extraction in a space charge limited mode [5-7]. They used electrostatic grids inside the plasma to separate the ion flow from plasma electrons. In this case, space charge effects limited the extracted ion current, as it would be with a thermionic ion source. When the beam current, limited in this way, fell lower than the minimum of the fluctuating value, a "noise free" stable ion beam was observed. Based on this idea of using electrostatic grids, the GSI-MEVVA-4 ion source has recently been modified and a substantial decrease in the noise level was observed [8].

In this paper we report on the results of some investigations of the space charge limited mode of operation of the LBNL MEVVA-5 ion source, particularly as relevant to its possible application in the heavy ion fusion research program.

II. EXPERIMENTAL SET-UP

The experiments were carried out at Berkeley using a multi-cathode broad beam vacuum arc ion source (Fig. 1) that has been described in detail elsewhere [9]. The pulsed vacuum arc (200 A, 250 μs) between cathode and anode was triggered by flashover discharge across a ceramic surface. Ions were extracted from the broad plasma surface through approximately 250 holes of 4 mm diameter in the end of the hollow anode (i.e., plasma electrode of the multi-aperture ion extraction system). A change from the conventional MEVVA-5 design was two fine stainless steel meshes that were assembled inside the hollow anode. The woven wire meshes had a wire distance of 250 μm and a wire thickness of 100 μm. For reasons of mechanical stability, each of the fine meshes were mounted on a stainless grid that had holes of 4 mm diameter and a distance of 5.5 mm between hole centers. The total geometrical transparency of the two meshes including holding grids was about 10%. Mesh 1 was located approximately 6 cm from the cathode surface and was biased positively with respect to the anode. Mesh 2, located 7 cm from the cathode and thus 1.0 cm from mesh 1, was kept at anode potential.

As pointed out by Humphries, plasma electrons are separated from ions in the gap between the meshes when bias voltage is applied to mesh 1. The ion flow that drifts from mesh 2 to the extraction electrodes is limited by its own space charge, which is no longer neutralized by electrons. Thus the total ion beam current is determined by space charge limited processes and is not affected by fluctuations whose origins are the explosive nature of vacuum arc plasma generation at cathode spots.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Influence of the potential of mesh 1 on the total ion beam current for the case of a platinum ion beam is illustrated by the development of the pulse shapes shown in Fig. 2. One can see a clear decrease of the noise level by about a factor of ten or more. In this mode of operation a beam current noise level of $\Delta I/I < 3\%$ can be obtained within each pulse. As the mesh bias is increased, initially the beam current falls to a minimum value and then increases up to nearly the zero-voltage value but now with significantly reduced beam noise (Fig. 2).

An initially surprising further observation is the effect of mesh bias on the ion charge state distribution. As the bias is increased, initially the high charge state fraction is reduced, subsequently returning to close to its initial value (Fig. 3). Thus the mean ion charge state in the ion beam has a minimum (Fig. 4).

The behavior of the ion beam current and a model of space-charge-limited ion flow can explain the noise level as a function of mesh voltage. It would seem at a first thought, the fraction of singly charged and multiply charged ions (i.e. the ion charge state distribution) should not change as they are decelerated and then accelerated by the same voltage hump. However, one should bear in mind that the initial ion directed velocity in the flowing plasma. are high, corresponding to kinetic energies of some tens of electron volts [10]. We have shown previously [11, 12] that the ion directed velocities in vacuum arc plasmas are the same for all charge states for a given material. This feature seems to be a key to understanding the experimental results. The potential hump is a barrier to ions and its effect should be most significant if ions of high kinetic energy but low charge state can overcome the barrier while multiply charged ions cannot overcome the barrier.

For the case of a Pt beam only the singly- and doubly-charged ion species need to be taken into account. To describe the situation when a two-component ion flux moves in an electrostatic field under the influence of its own charge space, we use a conventional system of equations (Poisson, continuity and motion):

$$
\begin{aligned}
&\Delta\varphi = -4\pi e(n_1 + n_2) \\
&\frac{\partial n_1}{\partial t} + div(n_1 v_1) = 0 \\
&\frac{\partial n_2}{\partial t} + div(n_2 v_2) = 0 \\
&\frac{\partial v_1}{\partial t} + (v_1\nabla)v_1 = -\frac{e}{m}\nabla\varphi \\
&\frac{\partial v_2}{\partial t} + (v_2\nabla)v_2 = -\frac{2e}{m}\nabla\varphi
\end{aligned}
$$

where n_1, n_2, v_1, v_2 are the densities and velocities for singly- and doubly-charged ions respectively, and φ is the potential in the ion drift region.

A two-dimensional approximation of the process was used. The initial ion flow was located within an angle of $\pi/3$ with a distribution given by the "cosine law". The absolute value of the initial ion directed velocity was the same for both charge states and corresponds to kinetic drift energy of 47 eV [12]. Different ion charge states with the same initial velocity are accelerated by the bias voltage and move across the drift space between mesh 2 and the plasma electrode of the extraction system. The space charge of the ion flow creates a potential barrier downstream of mesh 2. Ion charge state distributions were calculated for the case of the maximum ion current that can overcome the potential barrier. The system of equations was solved numerically by using a 5-point differential scheme. The calculated mean ion charge states are shown in Fig. 4 compared to the experimental data. One can see a surprisingly good agreement between our proposed model and the experiments although space charge compensation by secondary electrons is neglected. We conclude that a peculiarity of the vacuum arc plasma, namely that the ion drift velocity for a given material is independent of the ion charge state, is responsible for the influence of the mesh voltage on the final ion charge state distribution. Testing the model for the case of zero initial ion velocity did not show any dependence of the ion charge state distribution on the mesh voltage.

ACKNOWLEGMENTS

This work was supported by a research contract between LBNL and both HCEI and TUSUR provided by the DOE IPP Thrust-1 program, by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098, and by the Russian Foundation of Basic Research under Grant No. 99-02-18163.

References

1. I.G. Brown and E.M. Oks, IEEE Trans. Plasma Sci., **25**, 1222 (1997).
2. I.G Brown, A. Anders, S. Anders, M.R. Dickinson, R.A MacGill and E.M. Oks, Surf. Coat. Technol., **84**, 550 (1996).
3. P. Spaedtke, Nucl. Instrum. Methods Phys. Res., **A 464**, 388 (2001).
4. A. Anders and J.W. Kwan, Nucl. Instrum. Methods Phys. Res., **A 464**, 569 (2001).
5. S. Humphries, Jr., and H. Rutkowsky, J. Appl. Phys., **67**, 3223 (1990).
6. S. Humphries, Jr., and C. Burkhart, Particle Accelerators, **20,** 211 (1987).
7. S. Humphries, Jr., C. Burkhart, S. Coffey et al, J. Appl. Phys., **59**, 1790 (1986).
8. E. Oks, P. Spaedtke, H. Emig and B.H. Wolf, Rev. Sci. Instrum., **65**, 3109 (1994).
9. I.G. Brown, Rev. Sci. Instrum., **65**, 3061 (1994).
10. J. M. Lafferty, Ed., *Vacuum Arcs – Theory and Application,* New York: Wiley, 1989.
11. A.S. Bugaev, V.I. Gushenets, A.G. Nikolaev, E.M. Oks and G.Yu. Yushkov, Zhurnal Tekhnicheskoi Fiziki, **70**, 37 (2000) in Russian; Translation: Technical Physics, **45**, 1135 (2000).
12. G.Yu. Yushkov, A. Anders, E.M. Oks and I.G. Brown, J.Appl. Phys., **88**, 5618 (2000).

Figure captions

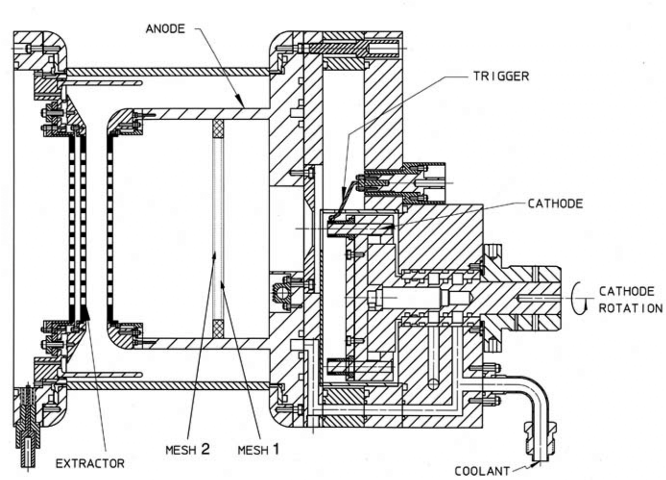
Fig.1. Schematic of the LBNL broad beam MEVVA-5 ion source with two meshes inserted.

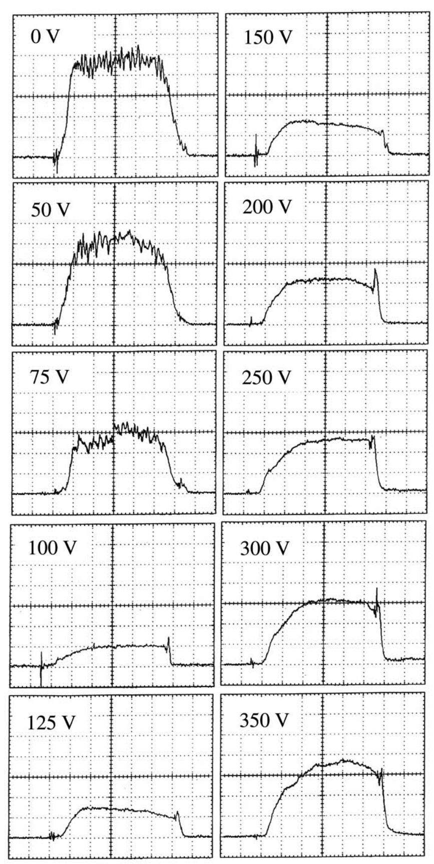
Fig.2. Development of the ion beam current pulse shape as determined by the mesh voltage for a platinum ion beam.

Fig.3. Influence of the mesh potential on ion charge state distribution of a platinum ion beam.

Fig. 4. Influence of the mesh potential on the ion mean charge state for a platinum beam.

1 – calculation, 2 – experiment.


ANODE
TRIGGER
CATHODE
CATHODE ROTATION
EXTRACTOR
MESH 2
MESH 1
COOLANT


0 V
150 V
50 V
200 V
75 V
250 V
100 V
300 V
125 V
350 V

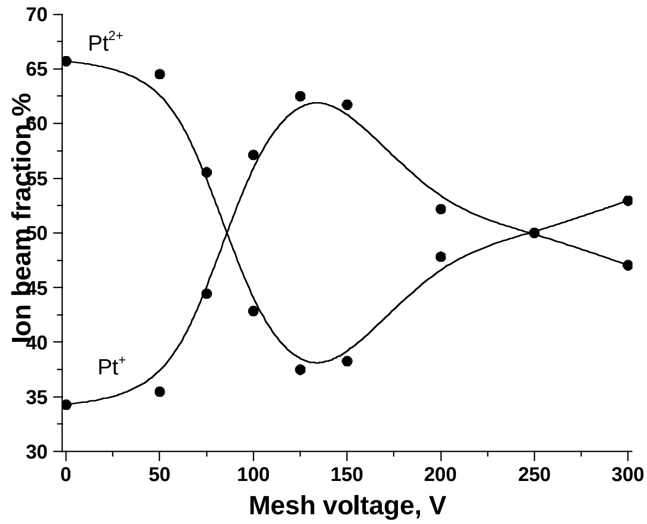


Fig.3. E.M. Oks et al "Further development of low noise MEVVA ion source.

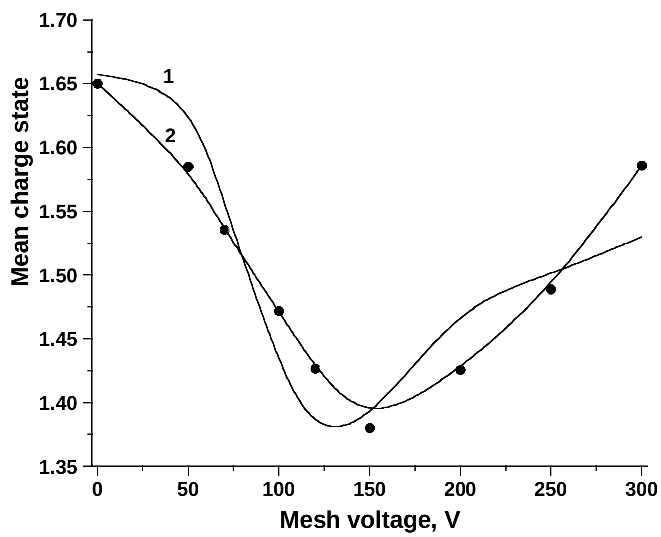


Fig.4. E.M. Oks et al "Further development of low noise MEVVA ion source.